1975

Bentonite or Sodium Bicarbonate in High-Concentrate Lamb Diets

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BENTONITE OR SODIUM BICARBONATE IN

HIGH-CONCENTRATE LAMB DIETS

by

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Animal Science, South Dakota
State University

1975

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor Date

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ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. R. J. Emerick, Professor of Chemistry and Dr. L. B. Embry, Professor of Animal Science, for their advice and guidance during the collection of data and preparation of this thesis.

Appreciation is also expressed to the Nutrition Unit workers and laboratory assistants who aided in various phases of this study, Dr. W. L. Tucker, Station Statistician, for his assistance in analysis of data and Carol Shally for her help in record-keeping and preparation of data for computer analysis.

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INTRODUCTION

A rapid change of ruminants from high-roughage diets, often used in background feeding programs, to high-concentrate diets used in the finishing phase tends to promote various digestive tract disorders. A major change in diets gradually made over a period of 3 to 4 weeks generally allows time for the rumen microflora to become adapted to the new conditions and minimizes digestive problems. However, performance during this period is often unsatisfactory.

In the short-term feedlot finishing of ruminants for slaughter, the importance of profitable weight gains during the initial adaptation phase of the feeding period becomes relatively more important. Methods of accelerating adaptation to high-concentrate diets are being studied; bentonite, a montmorillonite clay, and sodium bicarbonate are two of the materials that have received attention as potential feeding aids to be used for this purpose.

The purposes of the studies detailed in this thesis were to study the potential beneficial and detrimental effects of bentonite or sodium bicarbonate in adapting lambs to high-concentrate diets and to determine the effect of dietary bentonite on the digestion and retention of dietary nutrients.

REVIEW OF LITERATURE

Properties of silica and certain silica compounds

This topic has been extensively reviewed and documented by Iler (1955). Unless otherwise indicated, Iler's text is the source of information on silica and silica compounds.

Silica is omnipresent in the environment, comprising 60% of the earth's crust. Although it is not generally considered essential to life, some primitive life forms, such as plants of the *Equisteum* genus, diatoms and certain sponges utilize silica from their surroundings for the purpose of building skeletal structures. Varying quantities of silica can be found in most living organisms. In plants, silica in an amorphous form is deposited mostly in the cell walls. It is not usually found in high concentrations in the underground parts of plants (Lanning *et al.*, 1958). In certain species, silica apparently enhances resistance to fungal disease, and the presence of silica in certain types of soil can increase the amount of phosphorus available to plants. Silica is present in animal tissues, apparently in greater concentration in the hair, lungs, and kidneys than in other tissues (King and Stantial, 1933; King *et al.*, 1933; Sauer *et al.*, 1959). Recent work by Carlisle (1970, 1972) indicates that small quantities of silicon may be essential for normal growth of bones and some other tissues.

Amorphous silica (SiO_2) resembles a super-cooled liquid, with a molecular configuration similar to that of water. At body temperatures it is only slightly soluble in aqueous media (.01 to .015%). Silica dissolves in an alkaline solution when the pH is above 10.5 forming a silicate ion and silicon tetrahydroxide ($Si(OH)_4$). At low pH, the solubility of silica is enhanced by the reaction of $Si(OH)_4$ with acids, especially when the fluoride ion is present.

Solutions of silicic acid polymerize to form a sol of colloidal particles which then may continue an aggregation process to form a gel. The rate of polymerization is proportional to the square of the silica concentration. Usually a change in pH is a cause of this process and a decrease in temperature will cause the deposition of silica. Pure silica solutions are neutral (Kargin and Rabinovitch, 1935). In solutions where cations are present, the cations are absorbed by the colloidal particles, but there is no apparent exchange of absorption (Kargin and Rabinovitch, 1935). There is a wide variety of possible molecular configurations of silicic acid, e.g., linear or branched chains of SiO_4, cyclic structures, or compact spherical units. The gelling of silicic acid solutions can be prevented by adjusting pH to the alkaline side; polymerization occurs, but not gelling. In the absence of soluble salts, gel formation is practically prevented at pH 6 to 7; gelling occurs most rapidly at pH 5 to 6.

Aluminum has unique properties with respect to silica compounds. Aluminum can substitute for silicon in siloxane structures, forming aluminosilicates called zeolites. Zeolites are used as cation exchangers, as in water softeners. They are highly alkaline in nature. Lowering the pH by adding an acid results in removal of aluminum from the aluminosilicate and liberation of low molecular weight silicic acid.

Properties of sodium bentonite

Sodium bentonite is a clay consisting of 90% montmorillonite, a hydrous aluminum silicate (Iler, 1955). Montmorillonite has a sandwich type molecular structure, consisting of an octahedral sheet between two tetrahedral sheets (Iler, 1955). It consists of approximately 60% silica (SiO_2) by weight, 20% alumina (Al_2O_3) and a variety of other minerals in small quantities. A typical element composition by weight is: silicon, 30%; aluminum, 10%; sodium, 1.6%; magnesium, 1.7%; iron, 2%; and lesser amounts of potassium and calcium (American Colloid Company, Skokie, Illinois).

Sodium bentonite has an ion exchange capacity of 80 to 100 meq per 100 g (Bringe and Schultz, 1969), most of which is accomplished by sodium, hence the name sodium bentonite. Much work has been done in the field of soil science to substantiate the ion exchange properties of bentonite (Gast, 1969; Kurdi and Babcock, 1972; Murrman _et al._, 1968; Perkins, 1949; Webber, 1971; Webber and Clark, 1969; Zwarun _et al._, 1971). The compound will absorb five times its weight of water and will swell to 12 to 15 times its original dry bulk volume upon addition of water. Upon dispersion in water, bentonite forms fine particles; almost all the particles are finer than 44 μm in diameter, and half of the particles are finer than .1 μm (American Colloid Company, Skokie, Illinois). Apparently bentonite will disperse to particles in this range of sizes regardless of the consistency of the dry bentonite. The pH of the dispersions ranges between 8.5 to 10.1. The compound is used commercially in a variety of industries as a liner, thickener, binder, moisture barrier and as a colloid medium.

Soil ingestion by ruminants

Grazing ruminents may consume significant levels of soil with forage. Soil ingestion, as measured by fecal output of soil or silica, was reported by Healy (1974) to reach annual amounts of 75 kg for sheep and 600 kg for dairy cattle. Levels of soil ingestion have been reported to reach 780 g daily for grazing cattle (Thornton, 1974) and 198 g daily for grazing sheep (Field and Purves, 1964). These values represented 5.7% and 14%, respectively, of the daily dry matter intake of cattle and sheep. Healy (1973) reported the average amount of soil ingested to be approximately 2% of the fresh forage consumed; 2% of the fresh forage would be equivalent to about 14% of the dry matter intake.

Soil ingestion as a percent of feed intake increases during the winter months, and is inversely related to the plentitude of herbage (Arnold et al., 1966; Field and Purves, 1964; Healy et al., 1967; Healy and Ludwig, 1965; Ludwig and Healy, 1966). Soil type and the presence of earthworms are other factors affecting soil ingestion (Healy, 1973).

Daily fecal excretions of 380 g of silica for sheep on sparse winter pasture have been reported (Arnold et al., 1966). Analysis of the fecal silica indicated that it was almost entirely inorganic silica, and it composed up to 66% of the total daily fecal output. No respiratory ailments or nutritional diseases, e.g., siliceous urinary calculi, were reported over the 4-year span of their experiment. An increase in teeth wear is the most obvious effect of soil ingestion (Arnold et al., 1966; Healy and Ludwig, 1965; Healy et al., 1967), but the ingested soil may also serve as a source of microminerals (Healy, 1973).

The adsorption of several minerals to the rumen epithelium as a result of feeding pelleted diets containing 14% soil has been reported (Healy and Wilson, 1971). These deposits were removed by a 6 N hydrochloric acid solution. Although the mechanisms are not known at this time, the presence of soil in the ingesta apparently increases retention of several elements, such as calcium, magnesium, selenium, aluminum and cobalt (Healy, 1973; Healy et al., 1970).

<u>Silica digestion and metabolism</u>

The determination of silica digestibility as measured by fecal excretion compared to silica ingestion is difficult because there is a high variability in the digestion coefficient. Nottle (1965) observed a high variability in the digestion coefficient of silica and suggested a periodic variance in rumen silica retention, not a lower tract absorption, as the cause. Jones and Handreck (1965) found that the amount of silica in the urine and feces of sheep is within 1% of the amount of silica ingested, and that blood silica levels remained constant.

Nottle (1965) found that over a 10-day period the urine silica concentration and specific gravity were inversely proportional to urine volume. Changes in urine silica concentration have been suggested to be due more to the rate of urine excretion rather than dietary silica intake (Bailey, 1967a; Nottle, 1965). Jones and Handreck (1965) reported that the urinary silica excretion rate in sheep consuming diets containing up to 2.84% silica increased to a maximum of 205 mg per day, which they suggest is limited by the solubility of silica in the rumen. The silica in the rumen liquor of the sheep sampled reached a maximum level of 194 ppm.

Data reported for ruminants are supported by similar findings with guinea pigs (Sauer <u>et</u> <u>al</u>., 1959). Silica administered orally or intraperitoneally depolymerized to a soluble form before it was excreted in the urine. Upon reaching a maximum value, the silica level in the urine was not increased by increasing the dose of silica. Sauer <u>et</u> <u>al</u>.

(1959) proposed that the urinary excretion rate of silica is limited by its solubility in the contents of the gastrointestinal tract.

Siliceous urinary calculi

The occurrence of siliceous urinary calculi in ruminant species has long been recognized as a problem in the plains areas of northwestern United States, southwestern Canada and western Australia (Ensminger et al., 1955; Connell et al., 1959; Nottle and Armstrong, 1965). Forages in affected areas contain relatively high levels of silica (Bailey, 1973, 1969, 1967a; Bailey et al., 1963). A study of range conditions indicated a strong correlation between the silica content of range plants and the incidence of calculi (Parker, 1957). It was also reported in this study that variations in soil types affect the observed incidence of calculi. Weathered grasses such as those found during the winter months contain a higher level of silica. This is also the time of greatest soil ingestion as discussed elsewhere in this review. There are more cases of urolithiasis during the winter months than during the rest of the year in the North American plains (Parker, 1957), but in western Australia the most frequent occurrence of the ailment is during the hottest months of the year (Nottle and Armstrong, 1965).

The structure of siliceous calculi is similar to that of other types of calculi found in several species. Calculi are concretions of urinary crystalloids and colloids (Butt, 1952). The general morphology is a matrix of predominately mucoproteins in concentric laminations separated by layers of mineral salts (Boyce and King, 1959; Finco, 1971; Packett and Coburn, 1965; Cornelius and Bishop, 1961). Analyses of stones taken from range animals or animals fed prairie hay show that the principal mineral present is silica, usually composing more than half of the stone (Bailey *et al.*, 1963; Forman *et al.*, 1959; Keeler, 1963; Mathams, 1951; Romanowski, 1965; Puntriano, 1955; Swingle and Marsh, 1953). One study (Baker *et al.*, 1961) presented this general structural pattern: a central core rich in organic matter with minor quantities of dispersed opaline silica, a layer of opal with discontinuous strands of organic material and a thin continuous outer crust of organic matter with some opaline silica, strings of erythrocytes and possibly residues of bacteria. Embedded in the opaline silica are smaller types of opal phytoliths, silicisponge spicules and fragments of frustules of diatoms, all ostensibly ingested in the animal's feed and water. Results of another study (Keeler, 1960) show variations between extremes of laminated and non-laminated stones.

In spite of the knowledge of calculi formation in general, comprehension of renal functions and the capability to predict certain reactions of silica, the etiology of siliceous calculi is not well understood. Evidently siliceous uroliths will not form unless the concentration of urinary silica exceeds approximately 190 ppm (Bailey, 1967b; Settle and Sauer, 1960). Increasing water consumption and urine output by adding approximately 4% NaCl to a calculogenic diet has been shown to prevent calculi formation, apparently by lowering urinary silica concentration (Bailey, 1973, 1967b; Whiting *et al.*, 1958). However, efforts to induce urolithiasis by limiting water intake or by dietary supplementation of inorganic silica to ruminants have not been successful (Beeson *et al.*, 1943; Emerick *et al.*, 1959; Forman *et al.*, 1958; Keeler, 1963; Keeler and Lovelace, 1961, 1959; Swingle, 1953).

Persorption is defined by Brosig et al. (1972) as the urinary excretion of whole particles that are absorbed (persorbed) through the wall of the gastrointestinal tract. Persorbed particles have been shown to appear in the nucleus of oxalate calculi, possibly serving as a precipitory factor in calculi formation (Brosig et al., 1972). The structure of siliceous calculi as described earlier in this review (Baker et al., 1961) suggests persorbed particles may be present in siliceous calculi and that a similar mechanism may function in the formation of siliceous calculi, but it has not been experimentally substantiated.

Bentonite as a feed additive

Bentonite has been fed to domesticated animals as a dietary supplement for over 20 years. Work with rats (Laughland and Phillips, 1954a) and poultry (Blakely et al., 1955; Briggs and Spivey Fox, 1956; Laughland and Phillips, 1956) showed no detrimental effects of the compound on weight gain, but these reports indicate that bentonite may contribute to a vitamin A deficiency by adsorbing the vitamin in the digestive tract, thus making it unavailable. *In vitro* studies (Laughland and Phillips, 1954b) substantiate the claim of vitamin A adsorption, either in the vitamin form or as *Beta* carotene.

Feeding trials with lambs indicated that .1 lb of bentonite per head daily improved feedlot performance, but subsequent trials yielded inconclusive results (Bush and Jordan, 1956). Erwin et al. (1957) reported that 3% bentonite in the diet of steers had no effect on their feedlot performance, digestibility of dry matter, hepatic vitamin A content or carotene retention.

Burkitt (1969) observed feedlot ruminants consuming soil, and postulated that the animals were demonstrating a need for soil, or a constituent of the soil, in their diet. He then added 2% bentonite to the pelleted ration of feedlot heifers, and observed that the animals receiving bentonite in their diet consumed less soil than the controls. Addition of bentonite to the diet caused an initial relative improvement in feedlot performance. Bentonite has been reported to have beneficial effects on the feedlot performance of sheep in a study which included levels up to 8% of the diet (Martin et al., 1969). Bentonite has been reported to have an effect upon ruminal ammonia release (Rindsig and Schultz, 1970; Martin et al., 1969), rumen pH (Bringe and Schultz, 1969) and rumen volatile fatty acid concentrations (Bringe and Schultz, 1969; Rindsig et al., 1969). Its presence has been reported to improve the utilization of urea as a nitrogen source in the diet (Martin et al., 1969; McCullogh, 1974), but other reports indicate that bentonite decreases the digestibility and retention of dietary nitrogen in high-concentrate diets (Barney et al., 1974). Rindsig and Schultz (1970) reported that 5% and 10% bentonite in a high-concentrate dairy ration decreased the apparent digestibility of nitrogen, but increased nitrogen retention. Cows receiving bentonite excreted less urinary nitrogen than the controls. The addition of bentonite to corn silage at ensiling improved the available nitrogen level of the feed presumably through reduced silo seepage losses (Everson and Jorgensen, 1971).

Bentonite has been reported to lower calcium retention, but reports concerning phosphorus retention are conflicting (Martin et al., 1969; Rindsig and Schultz, 1970). Urine magnesium and sodium levels increased as a result of feeding bentonite in a high-concentrate ration (Rindsig and Schultz, 1970).

Beneficial effects of bentonite in poultry diets have been reported. It is credited with lowering moisture content in droppings and improving the feed per gain ratio of chicks, especially when incorporated in a relatively low energy diet (Kurnick and Reid, 1960; Quisenberry and Bradley, 1964). Part of the beneficial effect of bentonite may be due to a slower passage of feed through the digestive tract (Kurnick and Reid, 1960; Quisenberry and Bradley, 1964).

Sodium bicarbonate as a feed additive

Saliva is a natural source of bicarbonate that functions as a rumen buffer. Na^+ content of sheep saliva is similar to that of the blood serum, but saliva contains four times the serum level of HCO_3^- (McDougal, 1948). When saliva was diverted from the rumen of sheep, rumen pH fell and remained low 4 to 5 hr after feeding. Rumen volatile fatty acid (VFA) content rose and remained high for the same period. However, when saliva was allowed to enter the rumen, the pH and VFA levels initially followed the pattern described above, then returned to values similar to the prefeeding values (McManus, 1959). The effect of bicarbonate on rumen pH apparently is due to its effect on rumen VFA concentrations (Nicholson et al., 1960). Ruminants apparently secrete less saliva when consuming a high-concentrate diet than when consuming a high-roughage diet (Davis et al., 1964). Diet supplementation with sodium bicarbonate has been shown to decrease total VFA concentration in the rumen, thus maintaining a higher pH than would otherwise exist (Nicholson et al., 1963).

Sodium bicarbonate has been added to high-concentrate diets for ruminants in an effort to buffer the rumen pH against the acidic levels caused by such diets and to prevent related digestive disorders. Earlier work with ruminant diets containing approximately 50% roughage which were supplemented with alfalfa ash (the alfalfa ash contained high levels of potassium and sodium bicarbonate) showed that addition of the ash improved digestibility of the crude fiber portion of the diets (Chappell et al., 1955; Swift et al., 1951; Tillman et al., 1954b). A different study by Tillman et al. (1954a) indicated no effect on diet digestibility as a result of adding alfalfa ash.

The addition of 1% to 5% sodium bicarbonate to high-grain dairy cow rations has been shown to affect the ratio of VFA in the rumen (Emery et al., 1964; Davis et al., 1964; Thomas and Emery, 1969), and to increase or maintain the level of milk fat secretion (Davis et al., 1964; Emery et al., 1965; Ronning, 1968; Thomas and Emery, 1967). Rumen pH was increased in cows receiving bicarbonate supplement (Emery and Brown, 1961; Emery et al., 1964), as was urine pH (Emery et al., 1964). Bicarbonate supplementation can cause decreased grain intake in dairy cattle (Emery and Brown, 1961; Emery et al., 1964, 1965; Thomas and Emery, 1967), but these reports conflict concerning its effect on milk production.

Emery and Brown (1961) reported the incidence of bloat in dairy cattle fed buffered rations to be twice that observed in cows that did not receive bicarbonate supplementation. Oltjen and Davis (1965) found that the rumens of animals fed an alkaline buffered diet were 11% fuller than rumens of control animals, and that bloat was prevalent in the group receiving buffers. The addition of sodium bicarbonate to high-concentrate rations improved the average daily gain, dressing percent and carcass weight of steers, but one-third of the animals receiving the buffered diet died as the result of bloat (Preston et al., 1963).

Sodium bicarbonate at .5% to .75% has been added to the drinking water of steers of high-concentrate diets in an effort to provide rumen buffers. The buffered water has been reported to cause increased feed intake and rate of gain (Cullison and Ward, 1961) and increased water consumption (Lassiter and Alligood, 1967; Cullison and Ward, 1961; Lassiter and Cook, 1963). In the study by Cullison and Ward (1961), the steers without bicarbonate had significantly lower rumen pH than the steers drinking the buffered water. However, Lassiter et al. (1963) found that the buffered water had significant effects on rumen VFA ratios and on the rumen anaerobic count.

Results of adding sodium bicarbonate to high-concentrate diets fed to beef cattle vary among workers; it is difficult to compare the results of studies because different types and levels of buffers were fed. Preston et al. (1962) found no differences in feedlot performance as the result of supplementing 1.25% and 2.5% sodium bicarbonate in all-concentrate diets fed to holstein bull calves. However, 2.5% and 7.5% sodium bicarbonate increased dry matter intake and digestibility, and rumen and urine pH, with higher pH values being observed as the level of the buffer was increased. Wise et al. (1961) found that 11% buffers (4% $NaHCO_3$ + 7% $KHCO_3$) depressed the feedlot performance of calves. Addition of the buffer elevated rumen acetic acid levels, but did not affect other VFA levels. Lassiter and Alligood (1967) showed that sodium bicarbonate at levels up to 3% of a high-concentrate diet reduced feed intake proportional to the bicarbonate level in the diet. Other feeding trials involving 2% to 6% bicarbonate in high-concentrate diets have shown increased feed intake and gain (Nicholson and Cunningham, 1961; Nicholson et al., 1963; Wise et al., 1965), but at levels above this range buffers either did not improve performance, or had negative effects

(Nicholson and Cunningham, 1961; Nicholson et al., 1962a, 1963). Nicholson et al. (1962b) found no significant effects of 5.7% sodium bicarbonate on the apparent digestibility of nitrogen in a 5% fiber diet.

Results of studies with sheep in general concur with the results found with cattle concerning the effects of various levels of bicarbonate in high-concentrate diets (Lassiter and Cook. 1963; Lassiter et al., 1962; Kroman and Meyer, 1966; Saville et al., 1973). Kroman and Meyer (1966) explained an increase in digestibility of dry matter, protein and energy by sheep on buffered diets as being the result of a lower intake. The addition of .5% sodium bicarbonate to the drinking water of lambs consuming a 30% hay diet caused a significant increase in digestibility of ether extract and crude fiber (Lassiter and Cook, 1963). Supplementation of high-concentrate lamb diets with 2% sodium bicarbonate has been shown to raise urine pH and thereby contribute to the incidence of phosphatic urinary calculi (Hoar et al., 1969).

Reports cited in this review indicate that bentonite or sodium bicarbonate may aid in adapting ruminants to high-concentrate diets. Although substantial research has been conducted with sodium bicarbonate, the optimum amount and manner of feeding plus its effects on feedlot performance have not been conclusively established. The relationship, if any, between bentonite and the incidence of siliceous urinary calculi has not been defined; persorption of bentonite particles is a possibility that is worthy of investigation.

EXPERIMENTS 1 AND 2. STUDIES WITH SODIUM BENTONITE: INVESTIGATIONS OF ITS POTENTIAL BENEFICIAL AND DETRIMENTAL EFFECTS

Introduction

Grazing sheep and cattle may consume up to 14% of their annual dry matter intake as soil (Arnold et al., 1966; Field and Purves, 1964; Healy, 1973). Although this ingestion of soil by grazing animals apparently is involuntary, feedlot cattle receiving a high-concentrate diet have also been observed eating soil (Burkitt, 1969). This voluntary consumption under feedlot conditions decreased when sodium bentonite, a montmorillonite clay, was added to the diet. The feeding of bentonite had a beneficial effect on feedlot performance during the first weeks of the feeding period, indicating that perhaps bentonite aided in adapting the cattle to the high-concentrate diet.

A gradual change made over a period of several weeks is usually required to minimize digestive disorders that can occur in ruminants converted from high-roughage to high-concentrate diets. A rapid change from high-roughage to high-concentrate diets is likely to be associated with poor feedlot performance and even death losses.

The objectives of the studies detailed herein were: 1) to investigate the potential of sodium bentonite in inhibiting digestive disorders frequently associated with high-concentrate diets; and 2) to study digestion and metabolism of such diets as influenced by various levels of bentonite.

Experimental Procedure

Experiment 1. Prior to being placed on experiment, 240 crossbred wether lambs originating from Texas were vaccinated for the prevention of enterotoxemia and were drenched for control of internal parasites. The experiment was conducted for 110 days during the summer and early fall. The lambs were randomly allotted to 20 outdoor pens (12 lambs per pen) for five dietary treatments each replicated four times. The pens were 24 m^2 in area, equipped with automatic waterers and 4.9 m of bunk space per pen. The five dietary treatments were 0, 2, 4, 8 or 12% bentonite. The control diet consisted of corn, yellow, grain, grnd, (4), IRN 4-02-992, 74.5%; alfalfa hay, s-c grnd, (1), IRN 1-00-104, 20%; soybean, seeds, solv-extd grnd, mx 7% fiber, (5), IRN 5-04-604, 5%; trace mineral salt (6), .5%; and 2,200 IU vitamin A added per kg of diet. A diet sample, pooled from the various mixes prepared during the study, was analyzed by proximate analysis procedures and for selected minerals (table 1) (A.O.A.C., 1960).

"Volclay, BC grade" bentonite was used in these studies (generously provided by the American Colloid Company, Skokie, Ill.) and was added at the expense of the total diet. The bentonite used was 90% montmorillonite, a hydrous aluminum silicate. It had a dust-like consistency; 99% of the substance passed through a 100 μm sieve. It contained approximately 60% silica (SiO_2) by weight.

All pens were brought to full feed in 12 days and maintained on full feed for the duration of the experiment. The lambs were weighed at the onset of the trial, and at approximately 28-day intervals during

TABLE 1. PROXIMATE AND MINERAL ANALYSIS OF CONTROL DIET, DRY BASIS, EXPERIMENTS 1 AND 2

Item	%
Crude protein (N x 6.25)	13.2
Crude fiber	9.8
Ether extract	2.5
Ash	4.1
Nitrogen-free extract	68.3
Phosphorus	.29
Calcium	.31
Magnesium	.21
Sodium	.24
Potassium	.75
Silica (SiO_2)	.39

the experimental period. Records on average daily gain, average daily ration and feed per gain ratio were kept throughout the experiment.

Four lambs died during the experimental period; two lambs were from the control group, one from the 2% bentonite treatment and one from the 4% bentonite treatment. Post mortem examinations of all four lambs indicated that acidosis as a result of feed overload was the cause of death (South Dakota State University Veterinary Diagnostic Laboratory). The remaining 236 lambs survived the duration of the experiment.

On day 54 of the experimental period, blood samples were obtained from all surviving lambs. On day 106, blood samples were collected from five animals selected at random from each pen. The blood was obtained by jugular vein puncture, and the serum from each sample was frozen for later analysis.

Twenty-four hour urine collections were made from four lambs selected at random from each treatment during the 57th to 64th day of the experimental period. Urine pH was determined for each sample, then an aliquot was acidified with 12N HCl at the rate of 2% (v/v). The acidified aliquot was then strained and frozen for later analysis.

All lambs had access to feed up to the final weighing which was approximately 20 hr prior to slaughter. Carcass data were obtained after carcasses had been in the cooler about 24 hours. Kidneys and urine bladders were retained from all animals at slaughter and were examined for evidence of urinary calculi.

The calcium and magnesium contents of the urine and serum samples were determined by atomic absorption spectrophotometry, with the samples diluted in a .5% lanthanum solution to prevent phosphorus interference. Urine sodium and potassium contents were also determined by atomic absorption spectrophotometry. Urine and serum phosphorus levels were determined by the method of Fiske and Subbarow (Hawk et al., 1954). A molybdate-blue colormetric method was used to determine urine silica levels (Emerick et al., 1963).

Experiment 2. Forty-five crossbred wether lambs were allotted on the basis of weight to 15 indoor pens, three lambs per pen. The pens had slotted floors and occupied approximately 5.9 m^2 of floor space. The lambs were full fed the same five diets used in experiment 1 with three pens (total of nine lambs) per treatment. Water was available ad libitum.

On day 57 of the experimental period, four lambs from each of the five treatments (total of 20 lambs) were placed in metabolism cages. They were provided a daily ration equal to 3% of their body weights. After a 3-day adaptation period, urine and fecal excretions were collected for a 5-day period. The weight of the feces was recorded daily, and aliquots were retained and frozen for later analysis. The urine volume was recorded daily, urine pH was measured and an aliquot was acidified, strained and frozen in the same manner as the samples in experiment 1. The daily feed consumption was recorded for each lamb.

On day 73 of the experimental period four more lambs from each treatment were placed in the metabolism cages. The procedure for measuring and collecting samples and recording feed intake was the same as in the first collection period.

Between the two collection periods, blood samples were taken from all surviving lambs by jugular vein puncture. Serum was retained from each sample and frozen for later analysis. The daily water consumption by each pen was measured for 5 days beginning on day 82 of the experimental period.

On day 139 of the experimental period, the heaviest lamb from each pen was slaughtered. The interior of the rumen of each lamb was examined, and one lung from each lamb was retained and frozen for later analysis. The urinary bladder and kidneys of each lamb were examined for evidence of urinary calculi. Hot carcass weight and 24 and 48 hr cooler weights were obtained. On day 181 of the experimental period, all remaining lambs were slaughtered, and the same procedures were followed.

The serum and urine analysis procedures were the same as the ones used in experiment 1. Proximate analysis and phosphorus content of the feed and fecal samples were determined by A.O.A.C. (1960) procedures. Feed and fecal calcium, magnesium, sodium and potassium contents were determined by atomic absorption spectrophotometry on the acid soluble ash. Silica content of feed, feces and lung tissues was determined by gravimetric procedures (Piper, 1944).

Data collected in these experiments was analyzed using least-squares means analysis of variance procedures. Dunnett's t test was used to determine statistical significance between treatment means.

Results and Discussion

Experiment 1. Average daily gain (ADG), average daily ration (ADR) and feed per gain ratio (F/G) to date for each weigh period are shown in table 2. The addition of bentonite to the diet had an initial positive effect on the feedlot performance of these lambs, but the advantage was not sustained throughout the feeding period. The ADG for the 4% and 8% bentonite treatment groups was higher ($P<.05$) than the ADG for the controls during the first 28 days of the experimental period. However, there were no significant differences in ADG among the treatments for the remainder of the feeding trial. The ADR of lambs fed the higher levels of bentonite was consistently greater than for the controls. With the exception of the first 28 days, the higher feed intakes were accompanied by an increase in F/G. Although the higher levels of bentonite, especially the 8% and 12% levels, produced a very dusty feed, it apparently did not affect the palatability of the diets. The feed was so dusty that it is probable that a portion of the added bentonite was lost in the mixing, transporting, weighing and feeding process. Therefore, the diets may not have contained the full allotted amount of bentonite when fed.

Many of the control lambs appeared to experience digestive disorders during the first 28 days as is evidenced by erratic eating patterns and their high F/G ratio during that time. The data indicate that the feeding of bentonite was beneficial in this regard.

None of the bentonite treatments differed significantly from the controls in average carcass weight, grade, conformation, streaking, feathering or maturity.

TABLE 2. AVERAGE DAILY GAIN, AVERAGE DAILY RATION AND FEED/GAIN TO DATE, EXPERIMENT 1[a]

Weigh periods	Bentonite treatments				
	0	2%	4%	8%	12%
Period 1[b]					
ADG, kg	.094	.110	.183*	.194*	.140
ADR, kg	.976	.986	1.062*	1.008*	1.061*
F/G, kg	10.38	8.96	5.79*	5.61*	7.56
Period 2[c]					
ADG, kg	.191	.180	.224	.207	.182
ADR, kg	1.153	1.140	1.313**	1.353**	1.346**
F/G, kg	6.04	6.32	5.86	6.54	7.32*
Period 3[d]					
ADG, kg	.189	.180	.209	.202	.182
ADR, kg	1.267	1.270	1.400**	1.471**	1.475**
F/G, kg	6.71	7.04	6.70	7.29	8.10*
Period 4[e]					
ADG, kg	.191	.171	.203	.196	.179
ADR, kg	1.351	1.342	1.474**	1.557**	1.559**
F/G, kg	7.06	7.87**	7.26	7.96**	8.71**

[a]Values given in table are least-squares means.

[b]28 days.

[c]51 days to date.

[d]78 days to date.

[e]110 days to date.

*Significantly different from controls (P<.05).

**Significantly different from controls (P<.01).

Blood serum data (table 3) showed no significant differences in serum levels of calcium or phosphorus among the treatments at either the 54-day or 106-day collection. The 54-day data showed a trend towards lower serum magnesium levels as bentonite in the diet was increased, with the 4% and 12% bentonite treatment groups having lower (P<.05) levels than the controls. This trend was not evident at the 106-day collection. In fact, the 12% bentonite treatment group had a higher (P<.05) average serum magnesium level than the controls at this time. Statistical analysis of the changes in the mean serum levels of calcium and magnesium within treatments (a comparison of serum levels of lambs that were bled at both collections) showed that all bentonite treatment groups had increases (P<.05) in serum magnesium from the 54th to the 106th day of the experimental period. There were no significant changes in serum calcium levels except in the 12% bentonite treatment group where a decrease (P<.05) over the same period of time was observed.

Based on 24-hour collections (table 4), the 12% bentonite group had a lower (P<.05) average daily urine output than the controls. None of the bentonite treatment groups differed significantly from the controls in urine pH or in urine concentrations of phosphorus, magnesium, calcium, sodium or potassium. The urine concentration of silica increased as the level of bentonite in the diet increased, but the values were significantly higher only for the 4% and 12% bentonite treatment groups. Data presented by Nottle (1965) also shows an inverse relationship between urine output and urine silica concentrations in sheep,

TABLE 3. LEAST-SQUARES MEAN BLOOD SERUM LEVELS OF CALCIUM, MAGNESIUM AND PHOSPHORUS, EXPERIMENT 1

Item	Bentonite treatments				
	0	2%	4%	8%	12%
54-day collection[a]					
Calcium, mg/100 ml	9.7	9.7	10.2	9.8	9.7
Mangesium, mg/100 ml	2.9	2.9	2.7*	2.8	2.7*
Phosphorus, mg/100 ml	8.4	8.3	7.4	8.0	8.2
106-day collection[b]					
Calcium, mg/100 ml	9.7	9.4	9.7	9.7	9.3
Magnesium, mg/100 ml	3.2	3.4	3.3	3.0	3.4*
Phosphorus, mg/100 ml	9.7	9.6	9.3	9.2	9.4

[a]Samples from all surviving sheep (236 total).

[b]Samples from five sheep from each pen (120 total).

*Significantly different from controls (P<.05).

TABLE 4. LEAST-SQUARES MEAN DAILY URINE VOLUME, pH, AND MINERAL CONTENT, EXPERIMENT 1

Item	Bentonite treatments				
	0	2%	4%	8%	12%
Daily urine volume, ml	1303	802	1127	1045	663*
Urine pH	8.4	7.9	7.9	8.5	8.4
Calcium, mg/100 ml	2.2	2.3	3.1	2.0	6.0
Magnesium, mg/100 ml	65.7	68.0	69.4	72.7	131.8
Phosphorus, mg/100 ml	1.2	1.5	2.4	.9	1.0
Sodium, mg/100 ml	382	427	351	274	321
Potassium, mg/100 ml	496	553	528	412	659
Silica (SiO_2), ppm	67.5	104.0	141.5	120.5	210.2**

*Significantly different from controls (P<.05).

**Significantly different from controls (P<.01).

TABLE 4. LEAST-SQUARES MEAN DAILY URINE VOLUME, pH, AND MINERAL CONTENT, EXPERIMENT 1

	Bentonite treatments				
Item	0	2%	4%	8%	12%
Daily urine volume, ml	1303	802	1127	1045	663*
Urine pH	8.4	7.9	7.9	8.5	8.4
Calcium, mg/100 ml	2.2	2.3	3.1	2.0	6.0
Magnesium, mg/100 ml	65.7	68.0	69.4	72.7	131.8
Phosphorus, mg/100 ml	1.2	1.5	2.4	.9	1.0
Sodium, mg/100 ml	382	427	351	274	321
Potassium, mg/100 ml	496	553	528	412	659
Silica (SiO_2)	67.5	104.0	141.5	120.5	210.2**

*Significantly different from controls ($P<.05$).

**Significantly different from controls ($P<.01$).

but he reported the effect of increased urine volume in lowering urinary silica concentration to be reduced when urine volume exceeded 600 ml per day.

A review of experimental procedures and comparison of average daily urine output of the lambs in experiments 1 and 2 indicates that the lambs in experiment 1 were not accustomed to the metabolism cages in which the 24-hour collections were made, and that they were accustomed to drinking from automatic waterers instead of the watering cups available in the metabolism cages. Therefore in consideration of these factors, it is concluded that the urine output of the lambs in experiment 1 may not be indicative of their normal urine output, and that the data collected in experiment 2 are more representative of the normal situation.

Examination of the kidneys and bladders of the 236 lambs that were slaughtered showed that one lamb from the controls and one from the 8% bentonite treatment group had developed renal calculi. Analysis of the stones indicated they were the phosphatic type rather than siliceous stones. Factors contributing to phosphatic urinary calculi have been previously detailed (Emerick and Embry, 1969).

Experiment 2. Results of the balance trial are shown in tables 5 and 6. Apparent nitrogen digestibility decreased as the level of bentonite in the diet increased, with the digestion coefficient of the 12% bentonite treatment group being lower ($P<.05$) than the coefficient of the controls. The bentonite diets, while fed at a constant rate, provided progressively less nitrogen and more non-digestible dry matter

TABLE 5. LEAST-SQUARES MEAN DIGESTION COEFFICIENTS, BASED ON 100% DRY MATTER, EXPERIMENT 2

Item	Bentonite treatments				
	0	2%	4%	8%	12%
	Total ingested[a], grams				
Dry matter	4451	4797	4415	4255	4143
Nitrogen	94.2	99.0	89.0	82.4	76.2
Crude fiber	436	460	415	379	352
Ether extract	112	120	106	98	91
Nitrogen-free extract	3041	3204	2883	2655	2461
	Total excreted in feces[a], grams				
Nitrogen	28.8	31.7	30.9	29.9	30.5
Crude fiber	265	253	228	233	176
Ether extract	34	37	29	17**	19**
Nitrogen-free extract	343	340	327	388	359
	Digestion coefficients[b], percent				
Nitrogen	70	68	65	65	60*
Crude fiber	39	45	45	39	50*
Ether extract	70	68	72	83**	80**
Nitrogen-free extract	89	89	88	86	86

[a]Five-day totals.

[b] $\frac{\text{Intake} - \text{Fecal excretion}}{\text{Intake}} \times 100$ = Digestion coefficient.

*Significantly different from controls (P<.05).

**Significantly different from controls (P<.01).

TABLE 6. LEAST-SQUARES MEAN RETENTION OF DIETARY NUTRIENTS, FIVE-DAY TOTALS, EXPERIMENT 2

	Bentonite treatments				
Item	0	2%	4%	8%	12%
			Total intake, grams		
Nitrogen	94.2	99.0	89.0	82.4	76.2
Calcium	13.8	14.9	13.7	13.6	12.5
Magnesium	9.2	11.5	11.9	14.0**	15.7**
Phosphorus	13.0	13.4	12.3	11.1	10.4
Sodium	10.7	12.7	13.4	14.9**	17.0**
Potassium	33.2	35.2	32.2	30.2	28.6
			Total excreted in feces, grams		
Nitrogen	28.8	31.7	30.9	29.9	30.5
Calcium	9.1	9.9	10.0	8.4	8.7
Magnesium	3.4	3.2	3.5	3.9	3.8
Phosphorus	8.8	8.8	7.8	9.1	7.4
Sodium	2.2	3.0	2.8	4.0	3.0
Potassium	5.5	5.3	4.3	5.3	4.5
			Total excreted in urine, grams		
Nitrogen	36.7	40.0	36.7	36.7	33.8
Calcium	.1	.1	.1	.2	.2
Magnesium	3.5	3.4	3.0	3.6	3.0
Phosphorus	.2	.4	.5	.2	.2
Sodium	8.6	7.8	8.0	7.9	12.2
Potassium	23.4	22.0	17.7	17.8	17.1
			Total retained, grams		
Nitrogen	28.7	27.2	21.3	15.7*	11.9**
Calcium	4.6	4.9	3.6	5.1	4.0
Magnesium	2.3	4.9**	5.4**	6.5**	9.0**
Phosphorus	4.0	4.3	4.0	1.8**	2.8
Sodium	-.1	1.9	2.6	2.9	1.8
Potassium	4.3	7.9*	10.2*	7.1*	7.0*

*Significantly different from controls (P<.05).

**Significantly different from controls (P<.01).

per unit of feed as the amount of bentonite in the diet was increased. These conditions are usually accompanied by an increase in metabolic fecal nitrogen, and a decrease in apparent nitrogen digestibility would be anticipated (Maynard and Loosli, 1969). It is possible that the true digestibility of nitrogen was not adversely affected to the extent indicated by the apparent digestibility values.

Digestibility of the crude fiber portion of the diets was similar for the 2%, 4% and 8% bentonite treatment groups and the controls, but the coefficient for lambs on the 12% bentonite treatment was higher ($P<.05$) than that for the controls. The digestion coefficient for ether extract was higher ($P<.01$) for the 8% and 12% bentonite treatment groups compared to the controls. Digestibility of the ash portion of the diet decreased as the level of bentonite in the diet increased, indicating that the bentonite in the feed was for the most part present in the feces. There were no differences in the digestibility of the nitrogen-free extract portion of the diet among the treatments.

The amount of fecal silica within and among treatments was very erratic. Nottle (1965) reported similar variations in silica digestibility in sheep to be related to variations in rumen retention of silica. However, there is no direct evidence from this experiment regarding the effect of rumen retention on the digestibility of silica in the diets. Jones and Handreck (1965) postulated that the amount of silica in the urine and feces of sheep is within 1% of the amount of silica ingested.

Table 6 shows the balance data for nitrogen and several minerals. Nitrogen retention decreased as the level of bentonite in the diet increased, with the 8% ($P<.05$) and 12% ($P<.01$) bentonite treatment groups having lower retention than the controls. The decrease in nitrogen retention is similar to the results recently reported by Barney _et al._ (1974), a study in which the diet was similar to the one fed in this study. Rindsig and Schultz (1970) reported a decreased nitrogen digestibility, but increased retention as a result of adding 5% and 10% bentonite to a high-concentrate dairy cow ration. They reported a decreased urine nitrogen excretion in cows fed bentonite, but in the present study there were no differences in urine nitrogen excretion (table 6).

The bentonite caused an increased (P<.01) magnesium intake in the 8% and 12% bentonite treatment groups. There were increases (P<.01) in magnesium retention in all bentonite treatment groups compared to the controls. It is not known to what extent the higher magnesium content of the diet as a result of the added bentonite contributed to the increased magnesium retention. The bentonite used in this study contained 1.5 to 1.9% magnesium by weight (American Colloid Company).

The 8% bentonite treatment group had a lower (P<.05) phosphorus retention than the controls, and the lower phosphorus retention of the 12% bentonite treatment group approached statistical significance. There were no differences among the treatments in calcium retention. Other workers (Rindsig and Schultz, 1970; Martin _et al._, 1969) have reported added bentonite to affect calcium and phosphorus retention. All bentonite treatment groups had higher (P<.05) potassium retention than the controls. Lambs fed 12% bentonite diet excreted more (P<.01) urinary sodium than the controls, but the differences in sodium retention were not statistically significant.

Water consumption and urine data are presented in table 7. With the exception of the 8% bentonite treatment group, the lambs in the bentonite treatments drank more ($P<.05$) water than the controls. While daily urine volumes also tended to be higher for lambs in the bentonite treatments, they were quite variable and differences were not significant. There were no significant differences in urine pH among the treatments with urine pH averaging 8.2. Urine silica concentrations increased as the silica level in the diet increased, but did not approach the levels observed in the lambs in experiment 1. Nottle (1965), Nottle and Armstrong (1965) and Bailey (1967a) have presented evidence indicating that silica available for absorption and subsequent excretion in the urine is not necessarily proportionate to the amount of silica in the feed.

There were no significant differences in blood serum levels of calcium, magnesium, or phosphorus among treatments (table 8).

One lamb from the controls, four from the 2% bentonite treatment groups and one from the 12% bentonite treatment group had kidney or bladder calculi at the time of slaughter, or at the time of death in the case of three lambs that did not survive for the duration of the experiment. Analysis of the stones recovered indicated that all were of the phosphatic type, and chi-square analysis showed no significant differences among the treatments in the incidence of urinary calculi.

The carcass data, presented in table 9, showed no significant differences among the treatments in dressing percent, 24 or 48 hr

TABLE 7. LEAST-SQUARES MEAN DAILY WATER INTAKE, URINE VOLUME, URINE pH AND URINE SILICA CONCENTRATION, EXPERIMENT 2

	Bentonite treatments				
Item	0	2%	4%	8%	12%
Water consumption, ml	2425	3051*	2706*	2459	2674*
Urine volume, ml	658	859	1012	978	1168
Urine pH	7.9	8.2	8.2	8.0	8.6
Urine silica, ppm	103	97	182	161	160

*Significantly different from controls (P<.05).

TABLE 8. LEAST-SQUARES MEAN BLOOD SERUM LEVELS OF CALCIUM, MAGNESIUM AND PHOSPHORUS, EXPERIMENT 2

	Bentonite treatments				
Item	0	2%	4%	8%	12%
Calcium, mg/100 ml	9.8	10.0	9.9	9.9	9.6
Magnesium, mg/100 ml	3.6	4.0	3.6	3.1	3.0
Phosphorus, mg/100 ml	7.4	8.0	8.4	7.3	8.1

TABLE 9. AVERAGE DRESSING PERCENTAGE AND COOLER SHRINK OF CARCASSES, EXPERIMENT 2

Item	Bentonite treatment				
	0	2%	4%	8%	12%
Live wt. at slaughter, kg	56.4	55.7	54.7	49.1	49.7
Hot carcass wt., kg	30.2	30.0	28.7	25.5	25.9
Dressing %	53.5	53.9	52.5	51.9	52.1
24-hr cooler wt., kg	29.5	29.3	28.0	24.8	25.3
% shrink	2.32	2.33	2.44	2.75	2.32
48-hr cooler wt., kg	29.3	28.7	27.7	24.7	25.1
% shrink	3.00	4.33	3.48	3.14	3.09

carcass shrink. No abnormalities were observed in the rumen epithelium of any of the lambs.

Analysis of the lung tissue collected at slaughter showed no significant differences in lung silica content of lambs on bentonite treatments when compared to the controls, indicating that the extreme dustiness of the bentonite diets did not cause an accumulation of silica in the respiratory tract of these lambs. Noticeable dust was stirred up in the feed bins as the animals ate, however, and some mucus build-up was observed around the nostrils of the sheep eating the diets containing the higher levels of bentonite. One animal died as a result of pneumonia (South Dakota State University Veterinary Diagnostic Laboratory), but this appeared to be unrelated to treatment.

Summary

Two experiments were conducted to determine the effects of bentonite on the feedlot performance of lambs, and on the digestion and metabolism of various nutrients.

A 20% roughage diet with 0, 2, 4, 8, or 12% bentonite was fed to 240 wether lambs for 110 days. Added bentonite improved average daily gain and the feed per gain ratio during the initial 28-day period of the trial, but there were no differences among the treatments in cumulative performance after this time.

Balance trial data showed that apparent nitrogen digestibility and retention decreased as the level of bentonite in the diet increased. Increased ($P<.01$) ether extract digestibility and decreased phosphorus

retention as a result of 8% or 12% bentonite in the diet was observed. Lambs on the 12% bentonite diet had higher ($P<.05$) crude fiber digestion coefficients than the controls. There was an increase ($P<.05$) in magnesium and potassium retention in lambs receiving bentonite.

There were no effects observed due to treatments on the dressing percent or carcass quality. Bentonite levels had no effects on carcass shrinkage 24 or 48 hr after slaughter. There were no differences among treatments in lung silica content or in the appearance of the rumen epithelium at the termination of the experiments.

It appears that bentonite has the potential of being used as a dietary ingredient to aid in the adaptation of lambs to high-concentrate diets without exerting any adverse effects. The optimum level for various types of diets and the form of bentonite best suited for this purpose are aspects that require further study.

EXPERIMENT 3. SODIUM BENTONITE OR SODIUM BICARBONATE AS POTENTIAL AIDS IN ADAPTING LAMBS TO HIGH-CONCENTRATE DIETS

Introduction

Ruminants often experience digestive disorders and suboptimal performance when changed from high-roughage to high-concentrate diets. A period of approximately 2 to 4 weeks is commonly required before the animals become adapted to the high-concentrate diet.

Objectives of the study detailed herein were to investigate the use of sodium bentonite, a montmorillonite clay, or sodium bicarbonate as aids in adapting lambs to a high-concentrate diet, and to determine their effectiveness with nonprotein nitrogen and soybean meal as sources of supplemental crude protein.

Experimental Procedure

Four hundred fifty crossbred lambs consisting of equal numbers of ewes and wethers originating from Texas were randomly allotted to 45 outdoor pens, five wethers and five ewes per pen. The pens were 24 m^2 in area, equipped with automatic waterers and 4.9 m of feed bunk space per pen. Prior to being placed on experiment, all lambs were vaccinated for the prevention of enterotoxemia and drenched for control of internal parasites. The lambs averaged 28.2 kg in weight at the onset of the feeding trial which lasted 98 days during the summer and early fall.

The experiment was conducted in a 3 x 5 factorial design. Variables included the following: no supplemental protein (NSP), soybean meal or urea factored with control, 2% or 4% bentonite, or 2% or 4% sodium bicarbonate. "Volclay, feed crumbles grade" bentonite was used in this study, generously provided by the American Colloid Company, Skokie, Ill. The sodium bicarbonate was provided compliments of Church and Dwight Company, Incorporated, New York, N.Y.

The composition of the control diet is shown in table 10. The diets were finely ground; 97% of the mix passed through a 4760 μm sieve, and 40% through a 2000 μm sieve. A diet sample, pooled from the various mixes prepared during the study, was analyzed by proximate analysis procedures and for calcium and phosphorus content (table 11). Proximate and phosphorus analyses were by A.O.A.C. (1960) procedures, and calcium analysis was by atomic absorption spectrophotometry. Bentonite or sodium bicarbonate was added at the expense of the total diet. Each of the 15 diets was fed to three pens of lambs, respectively.

The lambs were brought to a full feed over a period of approximately eight days by limiting intake initially to .45 kg per lamb per day and increasing the amount of feed by .068 kg per day. The lambs were weighed at 21-day intervals during the experiment, and records were kept on average daily gain, average daily ration and feed per gain ratio. The final weigh period was 14 days in length.

Blood samples were obtained by jugular vein puncture from three lambs selected at random from each pen on days 29 and 97 of the experimental period. Serum from each sample was frozen and stored for later analysis. Serum calcium and magnesium were determined by atomic absorption spectrophotometry in the presence of .5% lanthanum to prevent

TABLE 10. COMPOSITION OF CONTROL DIETS, AS FED BASIS, EXPERIMENT 3

Item	International Reference Number (IRN)	Protein source		
		NSP	SBM	Urea
Brome, hay, s-c mature, (1), %	1-00-889	8.0	8.0	8.0
Corn, yellow, grain, grnd, (4), %	4-02-992	90.2	85.7	89.47
Soybean, seeds, solv-extd grnd, mx 7% fiber, (5), %	5-04-604	---	4.6	---
Urea, 46% nitrogen, (5), %		---	---	.6
Calcium phosphate, dibasic, commercial (6), %	6-01-080	.2	---	.2
Limestone, grnd, mn 33% calcium, (6), %	6-02-632	.8	.9	.8
Potassium chloride, KCl, cp (6), %	6-03-756	.3	.3	.3
Sodium sulfate, $Na_2SO_4 \cdot 10\ H_2O$ cp, (6), %	6-04-292	---	---	.13
Trace mineral salt (6), %		.5	.5	.5
Vitamin A, 30,000 IU/g as vitamin A palmitate, (7)[a]		+	+	+
Vitamin E, 220 IU/g as alpha-tocopherol, (7)[b]		+	+	+

[a]1100 IU per kg of diet.

[b]22 IU per kg of diet.

TABLE 11. PROXIMATE AND MINERAL ANALYSIS OF CONTROL DIETS, DRY BASIS, EXPERIMENT 3

Item	Protein source		
	NSP	SBM	Urea
Crude protein, %	10.3	12.2	12.2
Crude fiber, %	4.9	4.8	5.2
Ether extract, %	3.6	3.1	3.2
Ash, %	4.0	4.2	4.0
Nitrogen-free extract, %	77.2	75.7	75.4
Calcium, %	.51	.53	.52
Phosphorus, %	.36	.32	.34

phosphorus interference. Serum phosphorus content was determined by the method of Fiske and Subbarow (Hawk *et al.*, 1954).

Thirty-one lambs died or were removed from the experiment when death appeared imminent. Apparent causes of these deaths are discussed later. When these lambs were removed from the experiment, performance data were adjusted. Weight gain data for the dead lambs were deducted, and feed consumption data were adjusted for death losses by subtracting an average value up to that time.

All surviving lambs had access to feed up to the time of final weighing, which was approximately 48 hr prior to slaughter. Urinary bladders and kidneys were retained at slaughter and later examined for evidence of urinary calculi. Carcass weights and grades were recorded.

Data collected were analyzed using a least-squares means analysis of variance procedure. Dunnett's *t* test was used to determine statistical significance between means for data as influenced by bentonite or sodium bicarbonate in the diet. Duncan's new multiple-range test was used to determine statistical significance for data as influenced by protein supplements.

Results and Discussion

Cumulative average daily gain (ADG), average daily ration (ADR) and feed per gain ratio (F/G) are shown in tables 12 and 13. Lambs on either level of bentonite or the lower level of sodium bicarbonate tended to have higher ADG than the controls during the initial 21-day period. During this period the lambs on 2% sodium bicarbonate diets

TABLE 12. EFFECT OF BENTONITE OR SODIUM BICARBONATE ON CUMULATIVE AVERAGE DAILY GAIN, AVERAGE DAILY RATION AND FEED/GAIN, EXPERIMENT 3[a]

Item	Treatments				
	Control	2% Bentonite	4% Bentonite	2% $NaHCO_3$	4% $NaHCO_3$
Period 1[b]					
ADG, kg	.100	.178	.146	.191*	.097
ADR, kg	.801	.870	.870	1.094	.854
F/G, kg	8.010	4.888	5.959	5.728	8.804
Period 2[c]					
ADG, kg	.167	.207*	.158	.159	.169
ADR, kg	.998	1.090*	1.075*	1.013	1.055
F/G, kg	5.976	5.266*	6.804*	6.371	6.243
Period 3[d]					
ADG, kg	.187	.216*	.178	.178	.182
ADR, kg	1.123	1.218	1.188*	1.112	1.145
F/G, kg	6.005	5.639	6.674*	6.247	6.291
Period 4[e]					
ADG, kg	.200	.223*	.188	.192	.195
ADR, kg	1.188	1.279*	1.230	1.168	1.198
F/G, kg	5.940	5.735	6.543*	6.083	6.144
Period 5[f]					
ADG, kg	.203	.217	.183*	.190	.185*
ADR, kg	1.209	1.324*	1.250	1.193	1.223
F/G, kg	5.956	6.101	6.831*	6.279	6.611*

[a]Values given in table are least-squares means.

[b]21 days.

[c]42 days cumulative.

[d]63 days cumulative.

[e]84 days cumulative.

[f]98 days cumulative.

*Significantly different from controls ($P<.05$).

TABLE 13. EFFECT OF PROTEIN SOURCE ON CUMULATIVE AVERAGE DAILY GAIN, AVERAGE DAILY RATION AND FEED/GAIN, EXPERIMENT 3[a]

	Protein source		
Item	NSP	SBM	Urea
Period 1[e]			
ADG, kg	.101	.142	.184
ADR, kg	.801	.867	1.026
F/G, kg	7.930	6.106	5.576
Period 2[f]			
ADG, kg	.148[c]	.183[b]	.184[b]
ADR, kg	.995[c]	1.058[b]	1.086[b]
F/G, kg	6.723[c]	5.781[b]	5.902[b]
Period 3[g]			
ADG, kg	.168[c]	.197[b]	.200[b]
ADR, kg	1.113[c]	1.161[bc]	1.198[b]
F/G, kg	6.625[c]	5.893[b]	5.990[b]
Period 4[h]			
ADG, kg	.188[c]	.203[b]	.209[b]
ADR, kg	1.165[c]	1.217[b]	1.255[b]
F/G, kg	6.197	5.995	6.005
Period 5[i]			
ADG, kg	.184[c]	.197[b]	.206[b]
ADR, kg	1.199[c]	1.240[bc]	1.279[b]
F/G, kg	6.516[d]	6.294[c]	6.184[b]

[a]Values given table are least-squares means.

[bcd]Values within rows not sharing a common superscript are significantly different (P<.05).

[e]21 days.

[f]42 days cumulative.

[g]63 days cumulative.

[h]84 days cumulative.

[i]98 days cumulative.

had higher (P<.05) ADG than the controls and ADG for lambs on 2% bentonite diets approached statistical significance. Lambs on 4% sodium bicarbonate diets experienced digestive disorders during this period as evidenced by a high incidence of diarrhea and the depressed performance of these lambs.

Lambs on 2% bentonite diets had higher (P<.05) feed intakes and ADG than the controls during periods two, three and four of the experiment, and a lower (P<.05, period 2) F/G ratio than the controls. In spite of initial weight gain advantages, cumulative ADG at termination of the experiment was not significantly higher for any of the treatments. Conversely, 98-day cumulative ADG and F/G were lower (P<.05) and higher (P<.05), respectively, for lambs on 4% bentonite or 4% sodium bicarbonate.

Previous studies with the addition of approximately 2 to 5% sodium bicarbonate to high-concentrate ruminant diets have shown sodium bicarbonate to increase feed intake and ADG (Nicholson et al., 1963; Preston et al., 1963; Saville et al., 1973; Wise et al., 1965). Sodium bicarbonate has been reported to raise rumen pH and affect rumen volatile fatty acid concentrations (Davis et al., 1964; Emery and Brown, 1961; McManus, 1959; Nicholson et al., 1963, 1960; Oltjen and Davis, 1965). Dietary supplementation of sodium bicarbonate at levels higher than 5% of the diet has been reported to depress feedlot performance (Kroman and Meyer, 1966; Nicholson et al., 1962a; Wise et al., 1961).

Data presented in table 13 indicate that a protein level response occurred among the protein sources. The crude protein level in the NSP diets evidently was not sufficient to promote growth at the rate observed with use of diets containing urea or SBM. Supplementation with urea or SBM resulted in higher ($P<.05$) ADG except during the initial period, in which there was high variation within protein sources. There were no differences in ADG or ADR between lambs receiving urea or SBM. However, a slight but significant ($P<.05$) advantage in cumulative 98-day F/G was noted for these fed urea compared to SBM.

Observation of data on cumulative 98-day ADG and F/G indicates that feedlot performance of lambs on bentonite diets supplemented with SBM tended to be superior to performance of lambs on urea-bentonite diets. However, the urea-sodium bicarbonate diet combination tended to result in improved performance in comparison to SBM-sodium bicarbonate diets.

Blood serum data (tables 14 and 15) showed that all lambs except those on 2% bentonite diets had lower ($P<.05$) serum calcium levels than the controls at day 29 of the experimental period, and that the serum calcium levels of lambs on both levels of bentonite or sodium bicarbonate were lower ($P<.05$) than those of the control lambs on day 97 of the experiment. A trend toward higher (nonsignificant) serum phosphorus levels generally accompanied the lower serum calcium levels related to bentonite or sodium bicarbonate diets. Higher ($P<.05$) serum magnesium levels were evident in lambs on 4% bentonite or 4% sodium bicarbonate diets at day 97 of the experiment. Analysis of data as

TABLE 14. EFFECT OF BENTONITE OR SODIUM BICARBONATE ON BLOOD SERUM CONTENT OF CALCIUM, MAGNESIUM AND PHOSPHORUS, EXPERIMENT 3[a]

Item	Treatment				
	Control	2% Bentonite	4% Bentonite	2% $NaHCO_3$	4% $NaHCO_3$
	29-day collection				
Calcium, mg/100 ml	9.62	9.58	9.07*	9.24*	8.35*
Magnesium, mg/100 ml	2.34	2.68	3.06	2.49	2.59
Phosphorus, mg/100 ml	8.50	8.98	9.35	9.74	10.39
	97-day collection				
Calcium, mg/100 ml	10.10	9.55*	8.34*	9.34*	7.70*
Magnesium, mg/100 ml	2.66	2.69	3.07*	2.71	2.92*
Phosphorus, mg/100 ml	9.82	9.76	10.57	10.39	10.85

[a]Values given in table are least-squares means.

*Significantly different from controls (P<.05).

TABLE 15. EFFECT OF PROTEIN SOURCE ON BLOOD SERUM CONTENT OF CALCIUM, MAGNESIUM AND PHOSPHORUS, EXPERIMENT 3[a]

Item	Protein source		
	NSP	SBM	Urea
	29-day collection		
Calcium, mg/100 ml	9.17	9.11	9.24
Magnesium, mg/100 ml	2.57	2.71	2.62
Phosphorus, mg/100 ml	9.46	9.05	9.66
	97-day collection		
Calcium, mg/100 ml	9.45[d]	8.56[c]	9.00[b]
Magnesium, mg/100 ml	2.75	2.92	2.76
Phosphorus, mg/100 ml	9.47[c]	10.53[b]	10.84[b]

[a]Values given in table are least-squares means.

[bcd]Values within rows not sharing the same superscript are significantly different (P<.05).

TABLE 15. EFFECT OF PROTEIN SOURCE ON BLOOD SERUM CONTENT OF CALCIUM, MAGNESIUM AND PHOSPHORUS, EXPERIMENT 3[a]

Item	Protein source		
	NSP	SBM	Urea
		29-day collection	
Calcium, mg/100 ml	9.17	9.11	1.24
Magnesium, mg/100 ml	2.57	2.71	2.62
Phosphorus, mg/100 ml	9.46	9.05	9.66
		97-day collection	
Calcium, mg/100 ml	9.45[d]	8.56[c]	9.00[b]
Magnesium, mg/100 ml	2.75	2.92	2.76
Phosphorus, mg/100 ml	9.47[c]	10.53[b]	10.84[b]

[a]Values given in table are least-squares means.

[bcd]Values within rows not sharing the same superscript are significantly different ($P<.05$).

influenced by protein source (table 15) showed that lambs on diets containing urea or SBM had lower ($P<.05$) serum calcium and higher ($P<.05$) serum phosphorus levels than lambs on NSP diets on day 97 of the experiment.

Data from experiments 1 and 2 of this thesis do not show the same pattern with respect to the effect of bentonite on serum calcium and magnesium levels, but it is not known to what extent other variables such as differences in the roughage content and protein source of the diets in the two studies may have affected the results.

There were no significant differences in dressing percent (experimental average was 52.5%) or in carcass grade among the bentonite or sodium bicarbonate treatments or protein sources in the experiment.

Thirty-five lambs had developed urinary calculi by the end of the experimental period as evidenced by urinary blockage (seven lambs) or by the presence of calculi in the urinary bladder and/or one or both of the kidneys at the termination of the experiment (28 lambs). Of those developing urinary calculi, one was from the controls, two were on 2% bentonite diets, four on 4% bentonite diets, nine on 2% sodium bicarbonate diets and 17 on 4% sodium bicarbonate diets. Analysis of the stones indicated that all but one lamb had developed phosphatic calculi; the stones from one lamb on the 2% bentonite treatment were approximately 54% silica (SiO_2) by weight, which is within the range of silica content of stones categorized as siliceous calculi (Bailey _et al._, 1963; Keeler, 1963; Swingle and Marsh, 1953; Puntriano, 1955). In view of the isolated nature of the one case of siliceous calculi, its association with the 2% bentonite treatment is considered to be coincidental.

The lower serum calcium and higher serum phosphorus levels evident in lambs on sodium bicarbonate and 4% bentonite diets are similar to serum calcium and phosphorus levels associated with the incidence of phosphatic urinary calculi (Bushman et al., 1965a, b). Addition of sodium bicarbonate to lamb diets has also been reported to raise urine pH (Hoar et al., 1969), another contributory factor in the development of phosphatic calculi in lambs (Bushman et al., 1965a, b; Emerick and Embry, 1964).

Polioencephalomalacia (PEM) was diagnosed as the cause of death (South Dakota State University Veterinary Diagnostic Laboratory) of nine lambs. The causes of PEM which occurred in the experiment are not clear. However, seven of the nine cases having occurred in lambs fed 4% bentonite suggests an association, albeit limited, with this treatment. Occurrence of the disease has been previously observed in feedlot ruminants (Jensen et al., 1956). In a review of this topic by Edwin and Lewis (1971), similarities between PEM and thiamine deficiency were noted, and thiaminase activity in the rumen or the presence of inhibitory analogs of thiamine were postulated to be contributory factors.

Response of lambs on this experiment to thiamine injections was not conclusive. Six lambs exhibiting symptoms of PEM were injected intravenously with 450 mg of thiamine HCl in aqueous solution; three of the lambs subsequently died, and three appeared to respond to the injections. One of these, while not recovering completely, survived the remainder of the experiment but was killed and tissues were obtained for examination. The lamb's brain showed evidence of PEM (South Dakota State University Veterinary Diagnostic Laboratory).

Five lambs developed synovitis, an arthritic condition (South Dakota State University Veterinary Diagnostic Laboratory), and were removed from the experiment. In addition to the lambs removed from the experiment, there were numerous lambs distributed throughout the treatment groups that appeared to be afflicted to a lesser degree, as evidenced by their manner of walking and their stance. The affliction was observed principally in the rear legs of the affected lambs.

Acidosis as a result of feed overload (three lambs) and unknown or accidental causes (seven lambs) were apparent causes for the remainder of the deaths (South Dakota State University Veterinary Diagnostic Laboratory).

Summary

Studies were conducted to compare the potential of bentonite or sodium bicarbonate as dietary aids in improving adaptation and subsequent performance of lambs on high-concentrate diets under various conditions of protein supplementation. Three protein variations including no supplemental protein (NSP), soybean meal (SBM) and urea were incorporated into a 3 x 5 factorial design with a control, 2% or 4% bentonite, and 2% or 4% sodium bicarbonate. The 15 treatments were replicated three times with 10 lambs per pen (total of 450 lambs).

The feeding of 2% bentonite or 2% sodium bicarbonate was beneficial in adapting the lambs to a high-concentrate diet during the initial 21 days of the trial as evidenced by average daily gain (ADG) and feed per gain (F/G) during this period. However, there were no differences in overall 98-day ADG of lambs on these diets versus the controls. The addition of 4% bentonite or 4% sodium bicarbonate lowered ($P<.05$) overall ADG in comparison to the controls. ADG of lambs on the lower protein (NSP) diets was depressed when compared to the performance of those receiving the urea or SBM diets. Bentonite was most beneficial when fed in combination with SBM, while sodium bicarbonate gave best results with urea.

Both levels of bentonite or sodium bicarbonate lowered ($P<.05$) blood serum calcium levels. Increases ($P<.05$) in serum magnesium levels were associated with the 4% bentonite and 4% sodium bicarbonate diets. Lambs receiving the SBM and urea diets had lower ($P<.05$) serum calcium levels and higher ($P<.05$) serum phosphorus levels than lambs on NSP diets.

Approximately 19% of the lambs on sodium bicarbonate diets died as a result of phosphatic urinary calculi or had developed calculi at the end of the feeding trial. Nine lambs died as a result of polioencephalomalacia, seven of which were on 4% bentonite diets.

There were no differences among protein variations or bentonite and sodium bicarbonate treatments in dressing percent or carcass grade.

SUMMARY

Results of experiments 1 and 3 indicate that adaptation of lambs to a high-concentrate diet was improved by adding 2% bentonite to the diet, as evidenced by improved weight gains and lower feed per gain ratio during the first weeks on such diets. However, the advantage in weight gains was not sustained throughout the feeding trials which lasted approximately 100 days.

Two forms of bentonite (feed-grade crumbles and a finely ground powder) were used in these experiments. Both forms were equally effective at 2% of the diet in adapting lambs to high-concentrate diets.

Higher levels of bentonite (up to 12% of the diet) did not have consistent beneficial effects on feedlot performance of lambs. Fewer nutrients per unit of feed were available to lambs consuming diets containing bentonite since it was added at the expense of the total diet. Higher feed per gain ratios were apparently caused by this dilution effect. Added bentonite did not affect palatability of the diets since no negative effect on feed intake was observed.

Addition of bentonite to the diet of the lambs in experiment 2 adversely affected apparent nitrogen digestibility. An increase in metabolic fecal nitrogen as a result of increased nondigestible dry matter in the bentonite diets is suggested as a possible factor contributing to decreased apparent nitrogen digestibility. Digestibility of crude fiber and ether extract portions of the diet was enhanced by 8% and 12% bentonite in the diet, respectively, but the practicality of feeding bentonite at those levels is questionable.

Calcium retention was not affected by the addition of bentonite to the diet but 8% and 12% bentonite lowered phosphorus retention. Lambs on diets containing bentonite had higher magnesium retention and higher serum magnesium levels than control lambs. A relationship between the magnesium content of bentonite (approximately 1.7%) and the higher magnesium retention and serum levels observed is possible but not substantiated by these studies.

The presence of bentonite in the diet did not appear to have adverse effects on the rumen epithelium or the respiratory tracts of the lambs in experiment 2, although the addition of powdered bentonite caused a very dusty feed. Elevated silica (SiO_2) intake of lambs on diets containing bentonite did not promote siliceous urinary calculi. A limited association between dietary bentonite and the incidence of polioencephalomalacia in experiment 3 was observed.

The effect of 2% sodium bicarbonate in the diet on the feedlot performance of lambs in experiment 3 was similar to the effect of 2% bentonite. Lambs on 2% sodium bicarbonate diets had higher weight gains during the initial weeks of the feeding trial, but the advantage was not sustained. Sodium bicarbonate at a level of 4% proved to be detrimental to feedlot performance of lambs, as evidenced by their inferior weight gains and feed per gain ratio compared to the controls.

The incidence of phosphatic urinary calculi in experiment 3 was associated with the presence of sodium bicarbonate in the diet. Blood serum calcium and phosphorus patterns similar to those observed in this experiment have been reported in lambs fed calculogenic diets. Dietary sodium bicarbonate has also been reported to cause higher urine pH, another factor associated with urinary calculi.

Lambs on 2% and 4% bentonite diets containing soybean meal as a protein supplement (experiment 3) had higher overall average daily gains than lambs on similar diets containing urea instead of soybean meal. However, average daily gains of lambs on 2% and 4% sodium bicarbonate diets with urea were higher than those of lambs receiving similar diets with soybean meal.

Neither the presence of bentonite or sodium bicarbonate in the diet affected dressing percent or carcass grade of lambs in these studies.

It is concluded that the feeding of 2% bentonite or sodium bicarbonate may greatly enhance feedlot performance of lambs during adaptation to high-concentrate diets. However, continuous feeding of these materials throughout the feeding period appears to be of questionable value, and may be accompanied by some disadvantages especially when fed at levels higher than 4% of the diet.

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